



## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 7 :

H03L 7/183, 7/099

A1

(11) International Publication Number:

WO 00/35094

(43) International Publication Date:

15 June 2000 (15.06.00)

(21) International Application Number: PCT/US99/29083

(22) International Filing Date: 7 December 1999 (07.12.99)

(30) Priority Data:

60/110,557

7 December 1998 (07.12.98)

US

(71) Applicant (for all designated States except US): BROADCOM CORPORATION [US/US]; 16215 Alton Parkway, Irvine, CA 92618 (US).

(72) Inventors; and

(75) Inventors/Applicants (for US only): WAKAYAMA, Myles [US/US]; 16 Windham, Laguna Niguel, CA 92677 (US). JANTZI, Stephen, A. [CA/US]; 1245 Gaviota Drive, Upper Laguna Beach, CA 92651 (US). KIM, Kwang, Young [KR/US]; 6 Companero East, Irvine, CA 92620 (US). CHEUNG, Yee, Ling, "Felix" [CN/US]; 23556 Los Grandes Street, Aliso Viejo, CA 92656 (US). TONG, Ka, Wai [CN/US]; 23556 Los Grandes Street, Aliso Viejo, CA 92654 (US).

(74) Agent: ELDREDGE, John, W.; Christie, Parker &amp; Hale, LLP, P.O. Box 7068, Pasadena, CA 91109-7068 (US).

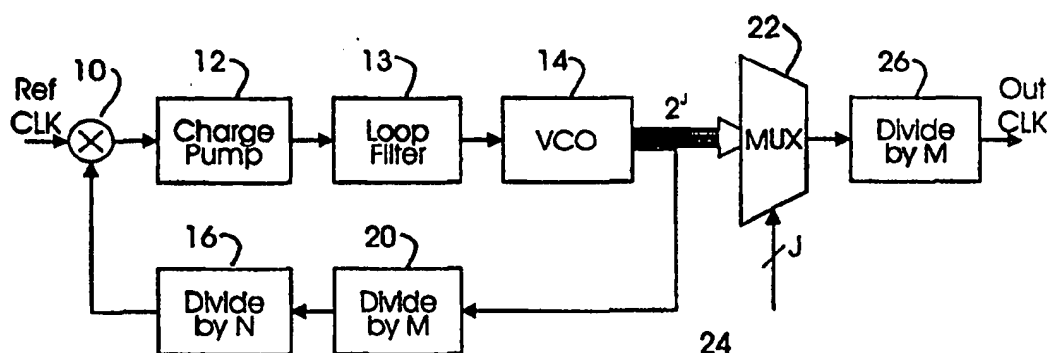
(81) Designated States: AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CR, CU, CZ, DE, DK, DM, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published

With international search report.

Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.

(54) Title: LOW JITTER HIGH PHASE RESOLUTION PLL-BASED TIMING RECOVERY SYSTEM



(57) Abstract

A low jitter, high phase resolution phase lock loop incorporating a ring oscillator-type VCO (14) is designed and constructed to operate at a characteristic frequency  $M$  times higher than a required output clock frequency. Multi-phase output signals are taken from the VCO and selected through a Gray code MUX (22), prior to being divided down to the output clock frequency by a divide-by- $M$  frequency divider circuit (26). Operating the VCO at frequencies in excess of the output clock frequency, allows jitter to be averaged across a timing cycle  $M$  and further allows a reduction in the number of output phase taps, by a scale factor  $M$ , without reducing the phase resolution or granularity of the output signal.

*FOR THE PURPOSES OF INFORMATION ONLY*

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	ES	Spain	LS	Lesotho	SI	Slovenia
AM	Armenia	FI	Finland	LT	Lithuania	SK	Slovakia
AT	Austria	FR	France	LU	Luxembourg	SN	Senegal
AU	Australia	GA	Gabon	LV	Latvia	SZ	Swaziland
AZ	Azerbaijan	GB	United Kingdom	MC	Monaco	TD	Chad
BA	Bosnia and Herzegovina	GE	Georgia	MD	Republic of Moldova	TG	Togo
BB	Barbados	GH	Ghana	MG	Madagascar	TJ	Tajikistan
BE	Belgium	GN	Guinea	MK	The former Yugoslav Republic of Macedonia	TM	Turkmenistan
BF	Burkina Faso	GR	Greece	ML	Mali	TR	Turkey
BG	Bulgaria	HU	Hungary	MN	Mongolia	TT	Trinidad and Tobago
BJ	Benin	IE	Ireland	MR	Mauritania	UA	Ukraine
BR	Brazil	IL	Israel	MW	Malawi	UG	Uganda
BY	Belarus	IS	Iceland	MX	Mexico	US	United States of America
CA	Canada	IT	Italy	NE	Niger	UZ	Uzbekistan
CF	Central African Republic	JP	Japan	NL	Netherlands	VN	Viet Nam
CG	Congo	KE	Kenya	NO	Norway	YU	Yugoslavia
CH	Switzerland	KG	Kyrgyzstan	NZ	New Zealand	ZW	Zimbabwe
CI	Côte d'Ivoire	KP	Democratic People's Republic of Korea	PL	Poland		
CM	Cameroon	KR	Republic of Korea	PT	Portugal		
CN	China	KZ	Kazakstan	RO	Romania		
CU	Cuba	LC	Saint Lucia	RU	Russian Federation		
CZ	Czech Republic	LI	Liechtenstein	SD	Sudan		
DE	Germany	LK	Sri Lanka	SE	Sweden		
DK	Denmark	LR	Liberia	SG	Singapore		
EE	Estonia						

1 LOW JITTER HIGH PHASE RESOLUTION PLL-BASED  
TIMING RECOVERY SYSTEM

CROSS-REFERENCE TO RELATED APPLICATION(S)

5 This application is related to co-pending provisional application Serial No. 60/110,557, filed December 7, 1998, entitled "LOW JITTER HIGH PHASE RESOLUTION PLL FOR GIGABIT ETHERNET", commonly owned by the Assignee of the present invention, the entire contents of which are expressly incorporated herein by reference.

10 FIELD OF THE INVENTION

The present invention is directed to high speed timing recovery systems and, more particularly, to a low jitter, high phase resolution timing recovery system.

BACKGROUND OF THE INVENTION

15 The past several years have witnessed a dramatic increase in the capabilities of high-speed, high-density broadband data communication systems. Pertinent such systems range anywhere from broadcast or cablecast HDTV systems, local area and wide area (LAN, WAN) systems for multimedia, fiber to the home (FTTH) applications and board-to-board interconnections in exchange systems and computers.

20 In any one of the foregoing applications, it should be noted that bidirectional data communication is in digital form and, accordingly, clock and data recovery circuitry is a key component to the efficient functioning of modern data communications systems. The ability to regenerate clock information from binary data is an inherent advantage in processing information digitally, as opposed to processing such information in its analog form. However, in order that  
25 an intelligent signal be correctly reconstructed at a receiver, binary data must be regenerated with the fewest possible number of bit errors, requiring receive data to be sampled at an optimum sample rate and at an optimal instance of time, i.e., accurately with respect to both frequency and phase. Given the bandwidth constraints imposed on most modern data communications systems, it is generally impractical to transmit sampling clock information separate from a transmitted  
30 datastream. Timing information is consequently derived from the incoming transmitted data signal itself. Extraction of an implicit timing signal is generally termed timing recovery (or clock recovery) in its functional role in general digital receiver technology, and is traditionally performed by some form of a phase-lock-loop system.

35 Also pertinent to binary data regeneration, is the understanding that noise corruption of narrowband signals represents a common situation in communication systems. Noise corruption occurs, for example, in satellite transceivers where intelligence signals, weak with respect to noise components, must be detected by coherent demodulation. In order to achieve a high signal-to-noise ratio (SNR), the noise components around a carrier must be suppressed, implying the

1      need for a narrow band filter. However, in most applications, the required filter bandwidth is several orders of magnitude smaller than typical carriers, thereby demanding relatively large filter quality factors (Qs). A phase-lock-loop (PLL) is able to operate as a narrow band filter with an extremely high Q.

5            In many applications which require multi-phase sampling, such as clock and data recovery, frequency synthesis, clock synchronization, and the like, PLL systems commonly employ ring oscillators, either single-ended or differential, as a frequency and phase generation circuit (voltage controlled oscillator or VCO). In many such applications, clock signals are generated to drive mixers or sampling circuits in which the random variation of the sampling instant (jitter) is a critical performance parameter. In certain applications, the frequency domain equivalent of jitter (termed phase noise) is also important. Jitter can arise from many sources, including inadvertent injection of signals from other parts of a circuit through the power supply. The inherent thermal and/or shot noise of the active and passive devices that make up a VCO cell, and, particularly, the sub-harmonic frequencies of the clock signal itself mixing into the desired output signal.

15           This last becomes an important design parameter when in it is recognized that modern digital clock recovery systems often require multiple clock phases to be provided at a single frequency in order that a clock recovery system might select the clock phase which best matches the particular phase of an incoming signal. The more clock phases available, i.e., the higher the phase resolution, the more precisely an incoming signal can be sampled and the better the overall system performance.

20           However, it is well recognized that in a VCO design with multiple clock phase outputs, the opportunities for random variation in the triggering edges, due to inter-stage interaction, RMS voltage noise, cycle-to-cycle jitter, and the like increases. Thus, jitter increases (in a complex relationship) with the number of phase taps taken from a multi-phase VCO system. In addition, for large numbers of clock phases produced by a VCO, it becomes difficult to design a VCO which does not exhibit multiple modes of oscillation. Thus, even though ring oscillators have been proposed as suitable candidates for implementation as low-noise voltage-controlled oscillators in high-performance PLL systems, their implementation has been limited because of their generally characterized "high" phase noise.

30           Accordingly, there is a need for PLL systems that are able to provide multi-phase output signals with a high phase resolution, and with low jitter and low phase noise characteristics.

#### SUMMARY OF THE INVENTION

35           A high-speed, low-jitter, high phase resolution PLL circuit includes a detector for comparing a phase or frequency characteristic of an input signal, such as a reference clock signal, to a phase or frequency characteristic of a timing reference signal. A timing reference signal generator, such as a VCO, is connected in feedback fashion in order to provide a timing reference

1 signal to the detector. The timing reference signal generator is operatively configured to oscillate and thereby produce an output signal at a characteristic frequency which is an integral multiple of a desired output clock frequency. Frequency divider circuitry is provided and is coupled to receive the output signal from the VCO and reduce its characteristic frequency to a desired output  
5 clock frequency.

The PLL circuit further includes a loop filter coupled between the phase/frequency detector and the VCO, and develops a control voltage for controlling the operational frequency of the VCO. VCO is constructed to output multi-phase signals, with each phase signal oscillating at the characteristic frequency of the VCO, and each phase signal characterized by a phase  
10 relationship depending on a delay characteristic of a component delay cell making up the VCO. The number of phases represented by the multi-phase output signals are reduced by a scale factor M from the number of phases characteristically produced by a timing reference signal generator operating at a characteristic frequency substantially equal to the desired output clock frequency.

The PLL circuit further includes a phase select MUX, the phase select MUX selecting  
15 between and among the multi-phase signals in order to define a respective one of the multi-phase signals as the output clock signal. The phase select MUX is a Gray code MUX, the MUX selecting between and among the multi-phase signals in accordance with a phase control word, the phase control word changing states in accordance with a Gray code sequence. The phase control word has a characteristic bit width J, where J has a value mathematically dependent on  
20 the frequency scale factor M.

In a further aspect, the PLL circuit according to the invention includes frequency divider circuitry disposed between the VCO and the phase/frequency detector and frequency divider circuitry disposed between the MUX and an output. The first frequency divider circuitry divides the output signal of the VCO by a scale factor ( $N \times M$ ) in order to develop a frequency  
25 characteristic which is provided to the detector for the comparison with the frequency characteristic of an input signal. The second frequency divider circuit divides the output signal of the VCO (and thus the MUX) by a scale factor M in order to develop an output clock signal at a desired frequency. Timing jitter and phase noise is thus averaged over a timing cycle having a scale factor of M, while phase resolution granularity is retained.

### 30 DESCRIPTION OF THE DRAWINGS

These and other features, aspects and advantages of the present invention will be more fully understood when considered with respect to the following detailed description, appended claims, and accompanying drawings, wherein:

35 FIG. 1 is a semi-schematic, simplified block diagram of a high-speed phase-lock-loop system, configured to operate at a frequency M times higher than a required output clock frequency, in accordance with the present invention;

1           FIG. 2 is a semi-schematic, simplified block diagram of a multi-phase phase-lock-loop system, configured in accordance with the prior art;

          FIG. 3 is a semi-schematic, simplified block diagram of a PLL, including a multi-phase VCO;

5           FIG. 4 is a series of waveform diagrams illustrating the phase resolution relationship between the PLL of FIG. 2 and the multi-phase PLL according to the invention of FIG. 1;

          FIG. 5 is a simplified, semi-schematic block diagram of a divide-by-M model which illustrates VCO jitter averaged over M cycles; and

          FIG. 6 is a simplified, semi-schematic block diagram of a Gray code MUX suitable for  
10           implementation in a PLL according to the invention.

#### DETAILED DESCRIPTION OF THE INVENTION

          In accordance with the present invention, a low jitter, high phase resolution PLL employs a voltage controlled oscillator (VCO) which operates at a characteristic frequency M times higher  
15           than the characteristic frequency typically required for an output clock signal. Operating a multi-phase VCO at such a higher output frequency reduces the number of output phases which must be taken from the VCO by the same scale factor M. In addition to reducing the number of VCO output phases, the physical size of selection circuitry, such as a phase control MUX is also reduced by the scale factor M, while the number of phase control lines, controlling operation of  
20           the phase control MUX, are also able to be reduced by a scale factor related to the scale factor M.

          Since the number of VCO phase stages are able to be reduced, power supply and substrate noise injection is reduced as a consequence, resulting in a lower jitter VCO design. Because the number of output phases taken from a multi-phase VCO is reduced, the possibility of multi-mode  
25           oscillation is also reduced.

          A design for a low jitter, high phase resolution PLL is illustrated in simplified, semi-schematic block diagram form in FIG. 1.

          Phase-lock-loops operate to compare the frequency and/or phase of an incoming serial datastream to a periodic reference clock signal generated by an oscillator circuit, and further  
30           operate to adjust the operational frequency and phase characteristics of the oscillator until its output stream is "locked" in both frequency and phase to a data signal (or alternatively, to a reference clock signal). An output clock is thereby established which, in turn, controls operation of a decision circuit which regenerates (or retimes) the data signal. The phase-lock-loop suitably includes a phase detector 10 whose output is coupled to a charge pump circuit 12, operatively  
35           connected, in turn, to a loop filter 13 and a voltage controlled oscillator (or VCO) 14.

          A reference clock or data signal is received at a data input of a phase detector 10, in which the currents of the clock's rising edge (its phase) is compared in time to the occurrence of a rising edge (the phase) of an output signal of the VCO 14. According to convention, the phase detector

1 10 provides pump signals to the charge pump 12 depending on whether the data stream phase  
leads or lags the phase of a clock signal derived from the VCO 14. A control voltage is  
developed which is used to control the operational frequency of the VCO 14. The sign of the  
VCO control voltage variation depends on whether the phase of the datastream leads or lags the  
5 phase of the VCO output and the magnitude of the VCO control voltage is a function of the  
extent of the phase lead or phase lag.

Thus, the operational frequency of the VCO 14 is increased or decreased, as appropriate,  
to reduce the phase lead or the phase lag of the inputs of the phase detector 10. The phase-lock-  
loop thus ensures that the VCO output which is used as a timing reference, is locked in phase  
10 with the incoming serial datastream, or, in the case of the exemplary embodiment of FIG. 1, with  
a reference clock signal. Once the PLL is "locked", the timing reference signal, i.e., the output  
clock, is used to control operation of various decision circuits which define regenerated or  
retimed data.

Digressing momentarily to the simplified, semi-schematic block diagram of an exemplary  
15 embodiment of a multi-phase PLL of FIG. 2, a common design implementation of a high phase  
resolution PLL is to design a VCO with multiple clock phase outputs, such as a delay cell-based  
ring oscillator. In the exemplary embodiment of FIG. 2, in which common functional blocks  
share common reference numerals with the exemplary embodiment of FIG. 1, the VCO 14 is  
constructed to operate at a characteristic frequency, having a frequency multiplication factor, or  
20 scale factor N, relative to the frequency of an incoming reference clock signal. Accordingly, in  
order to "lock" the VCO's operating frequency to the frequency of the incoming reference clock  
signal, a particular output phase signal is chosen as representing the VCO output signal and  
directed through a divide-by-N circuit 16 prior to being combined with the incoming reference  
clock signal in the phase detector 10.

25 It should be noted that although the VCO 14 is configured to operate at a particular  
characteristic frequency, N times the ref clock frequency, the implementation of the VCO as a  
delay cell-based ring oscillator, allows a multiplicity of output signals to be developed, with each  
signal having the same characteristic operational frequency of the VCO, but with each signal  
differing from another by a characteristic phase relationship defined by the value of a delay cell,  
30 or an integral multiple thereof. Thus, in the exemplary embodiment of FIG. 2, the VCO is able  
to produce  $2^K$  clock phases, where K is an integer.

A signal bus, carrying the  $2^K$  multi-phase signals, is directed to a phase control MUX 18  
where signals with particular phase relationships are chosen in accordance with a phase control  
signal, in order to define an output clock signal having the particular frequency and phase  
35 relationship required to operate a decision device such as a DDFS, mixer, demodulator, and the  
like. It should be noted that the phase control signal, controlling operation of the phase control  
MUX 18, is implemented as a bus, where the bus has a signal width of K. Thus, individual ones

1 of the  $2^K$  multi-phase signals can be selectively chosen to define the output clock signal of the PLL.

5 In practice, the PLL of the exemplary embodiment of FIG. 2 might be used as a reference source for a high-speed decoder circuit or a high-speed ADC. Sampling inaccuracies due to phase offsets are able to be characterized and written to a register, for example. Phase offset words written to such a register might provide the source for the phase control signals directed to the phase control MUX 18. An observed phase lag or phase lead in an ADC, for example, can be compensated by choosing the appropriate one of the  $2^K$  signals in order to advance or retard the phase characteristic of the PLL's output clock signal so as to compensate the observed phase lead or phase lag of the ADC timing window.

10 Returning now to the exemplary embodiment of a PLL system of FIG. 1, the VCO 14 is also configured to operate at a characteristic frequency having a frequency multiplication factor  $N$  relative to an input reference clock signal, and is further implemented to operate at a frequency  $M$  times higher than the required output clock frequency, i.e., operating at a frequency multiplication or scale factor of  $M \times N$  relative to the input reference clock. As was the case with the PLL of FIG. 2, a VCO output signal is directed through frequency divider circuitry prior to being combined with an input reference clock signal in a phase detector 10. Frequency divider circuitry suitably includes a divide-by- $N$  circuit 16, as well as a divide-by- $M$  circuit 20. Although the frequency divider circuits are illustrated as being provided separately in the exemplary embodiment of FIG. 1, it should be understood that this is solely for purposes of ease of illustration. Frequency divider circuitry may be provided in a single circuit, or multiple circuits, so long as the various frequency multiplication factors, relative to an incoming reference clock signal, are accommodated.

25 Because the VCO 14 of the exemplary embodiment of FIG. 1 is operating at a frequency  $M$  times higher than the required output clock frequency, the number of output phases that the VCO needs to provide may be reduced by a scale factor  $M$ . The VCO 14 thus provides  $2^J$  output phase signals, where  $2^J = 2^K/M$ . The output phase signals are directed to a phase control MUX 22 where appropriate output phase signals are selected by a phase control signal bus 24, having a signal width  $J$  as will be described in greater detail below. Once an appropriate output phase signal is chosen from phase control MUX 22, an output clock signal is developed by directing the chosen signal through a divide-by- $M$  frequency divider circuit 26. The VCO 14 and phase control MUX 22, function to define an output signal having a particular desired phase state, while the divide-by- $M$  frequency divider circuit 26 functions to provide the particular phase date signal at the appropriate output frequency.

35 FIG. 3 illustrates, in simplified, semi-schematic block diagram form, an exemplary PLL with a VCO portion 14 implemented as a delay cell-based ring oscillator including multiple clock phase outputs. As was the case with the exemplary embodiments of FIG. 1 and 2, the VCO output is combined with a reference clock signal, for example, in a phase detector 10 in order to



1     derive a pump signal directed to charge pump 12. The charge pump 12 develops pump up and  
pump down signals through loop filter 13 in order to derive a control voltage which controls  
operational speed of the VCO 14 by controlling the delay of each of its component delay stages.  
Multi-phase sampling is performed by taking an output from the VCO 14 at particular selected  
5     ones of its various sequentially disposed delay stages. Each of the outputs will develop a signal  
having the characteristic oscillation frequency of the VCO, but having a phase relationship with  
preceding and following signals, with the phase relationship depending on the amount of delay  
present in the delay stage or stages between each successive output.

10     The particular relationship between output phase and output frequency is depicted in the  
waveform diagrams of FIG. 4, with the uppermost set of waveform diagrams representing output  
signals developed by a VCO operating at a conventional frequency  $N$  times the reference clock  
frequency. Four waveforms are illustrated in the upper portion of the exemplary embodiment of  
FIG. 4, with each waveform representing a signal taken from the VCO every  $90^\circ$  of phase.

15     The lower portion of the exemplary waveform diagram of FIG. 4 represents a multiplicity  
of output signals developed by a VCO, operating in accordance with principles of the present  
invention, in which the frequency of the VCO is  $M$  times higher than the frequency of the VCO  
represented in the upper portion, i.e., in the case of the exemplary embodiment of FIG. 4, the  
high-speed VCO is operating at 4 times the required output clock frequency. As will be evident  
from the waveform diagrams of FIG. 4, a high-speed VCO is able to develop a significantly  
20     larger number of transition edges within an output clock period than the relatively lower speed  
VCO such as might be represented by FIG. 2. Indeed, the high-speed VCO, such as might be  
represented by the exemplary embodiment of FIG. 1, is able to develop 17 transition edges,  
representing 17 quasi-phase states within the same output clock period in which 5 quasi-phase  
states are developed by the relatively lower speed VCO of FIG. 2.

25     In practical terms, this allows the number of physical output phase taps, from the VCO,  
to be reduced by a scale factor  $M$  (in the present case a scale factor of 4) while retaining the same  
phase resolution granularity of the relatively lower speed system.

30     Further, and in accordance with principles of the present invention, the physical size of  
the phase control selection MUX (22 of FIG. 1) is also able to be reduced by scale factor  $M$ , with  
the number of phase control lines represented mathematically by a value  $J = Kx (\log 2 / \log M)$ .  
It should be further recognized that the scale factor  $M$  should be chosen as a power of 2.

35     Since the number of stages in the VCO are able to be reduced, its power supply noise and  
substrate noise injection characteristics can also be reduced, resulting in a lower jitter VCO  
design. In the particular case where the VCO output frequency is  $M$  times the desired output  
clock frequency, it will be evident that VCO jitter is averaged over  $M$  cycles, as is depicted in the  
generalized block diagram of FIG. 5. In FIG. 5, each of the delay stages of an exemplary ring  
oscillator-type circuit is represented by a delay element  $Z^{-1}$  30 with each delay element's jitter  
contribution represented by a "delta timing" value  $\Delta T_{VCO}$ . Classical theory suggests that adding

1 a frequency divider between a VCO and an output node or phase detector, results in increasing  
VCO jitter as the division ratio M increases. Measured data, however, contradicts this classical  
prediction. A divide-by-M circuit (20 and 26 of FIG. 1) can be modeled by an M-bit-long shift  
register which is equivalent to cascading M-1 unit delay blocks 30 in the Z-domain. Since  
5 integration of the VCO period change  $\Delta T$  is performed on a cycle basis, the jitter at the output  
of the divide-by-M circuit (32 of FIG. 5) can be expressed as  $\Delta T_M = \Delta T_{VCO}/M$ . Thus, it should  
be clear that a divide-by-M circuit implements moving average filter, with little or no averaging  
performed at lower frequencies.

The architecture of the low jitter high-phase resolution PLL described in connection with  
10 the exemplary embodiment of FIG. 1, places few constraints on the system level implementation  
of a digital clock recovery system. However, as will be well understood by those having skill in  
the art, phase control must be incremented or decremented sequentially one step at a time. The  
random phase access of the exemplary PLL system described in connection with FIG. 2, is  
foregone in favor of the low jitter characteristics and high phase resolution of the PLL system  
15 according to the present invention. As those having skill in the art will appreciate, this is  
generally not an issue in communication systems which have a constant carrier link.

A further aspect of the present invention, which reduces substrate noise injection  
characteristics and reduces the "glitch" potential of the output clock when a phase control signal  
is changed in the phase control MUX (22 of FIG. 1), includes a Gray code implementation to the  
20 phase control MUX which promotes smooth and orderly transitions between phase states of the  
VCO. Such a Gray code MUX is depicted in semi-schematic simplified block diagram form the  
exemplary embodiment of FIG. 6. In particular, the MUX is implemented as a three bank  
cascade, with the first input bank constructed of four parallel MUX elements 34, 36, 38 and 40,  
with each of the input MUX elements configured to receive and select between two input signals,  
25 with each input signal representing a particularly phased signal, each signal being differential and  
each signal representing a 180° phase relationship. The choice between the MUX bank's first  
or second inputs(input 0 or input 1) is made by the most significant bit (the embodiment of FIG.  
6 bit-2) of the phase control word, having characteristic width J (in the exemplary embodiment  
of FIG. 6, having characteristic width of three bits). Once the input state of the input MUX bank  
30 is selected, the signals are directed to an intermediate MUX bank, including two parallel MUX  
elements 42 and 44, each configured to receive two input signals at their binary defined inputs  
(input 1 or input 0). The choice between binary input states of the intermediate MUX bank is  
made by the next most significant bit is made by the next most significant bit (bit-1) of the phase  
control word and the resulting signals are directed to the binary defined inputs of an output MUX  
35 46. The final choice of the particular phase of the signal to be developed as an output clock  
signal is made by the least most significant bit (bit-0) of the phase control word.

Thus, it will be understood that the Gray code MUX, in accordance with the present  
invention, allows for smooth transitions between selected output phases, by virtue of the

1 operation of a Gray code sequence. In a Gray code sequence, only a single bit is allowed to  
change from a previous state to a present state and from a present state to a subsequent state.  
Thus, there is only a limited opportunity for the switch logic circuitry of the phase control MUX  
to introduce noise and "glitch" opportunities into operation of the system.

5 In order to further improve system speed and minimize the system's sensitivity to power  
supply and substrate noise, and further reduce the system's susceptibility to "glitches" and jitter,  
the system's switch logic circuitry, such as the MUX and divide-by-M frequency divider  
circuitry, are implemented in current-mode-logic. However, it will be evident to one having skill  
10 in the art that the invention may likewise be suitably implemented in various other semiconductor  
technologies, such as bipolar, bi-CMOS, and the like, and may also be suitably implemented in  
various other logical forms, such as ECL, VML, and the like. Moreover, the various circuit  
elements according to the invention may be constructed from discrete components or as a  
monolithic integrated circuit, depending upon the particular needs of a communication system,  
or the desires of a system designer. Voltage controlled oscillator circuitry may be implemented  
15 as a ring oscillator-type VCO and might be constructed of either single ended or differential unit  
delay cells.

It will thus be recognized by those skilled in the art that various modifications may be  
made to the illustrated and other embodiments of the invention described above, without  
departing from the broad inventive scope thereof. It will be understood, therefore, that the  
20 invention is not limited to the particular embodiments or arrangements disclosed, but is rather  
intended to cover any changes, adaptations or modifications which are within the scope and spirit  
of the invention as defined by the appended claims.

## 1 CLAIMS

1. A phase lock loop comprising:  
a detector for comparing a phase or frequency characteristic of an input signal to  
a phase or frequency characteristic of a timing reference signal;  
5 a timing reference signal generator, connected in feedback fashion to provide a  
timing reference signal to the detector; and  
wherein the timing reference signal generator is operatively configured to produce  
an output signal at a characteristic frequency an integral multiple of a desired output clock  
frequency.  
10
2. The phase lock loop according to claim 1, further comprising a frequency divider  
circuit coupled to receive the output signal and reduce its characteristic frequency to a desired  
output clock frequency.
- 15 3. The phase lock loop according to claim 2, further comprising a loop filter coupled  
between the phase/frequency detector and the timing reference generator, the loop filter  
developing a control voltage for the timing reference generator.
- 20 4. The phase lock loop according to claim 2, wherein the timing reference generator  
is constructed to output multi-phase signals, each phase signal oscillating at the characteristic  
frequency.
- 25 5. The phase lock loop according to claim 4, further comprising a phase select MUX,  
the phase select MUX selecting between and among the multi-phase signals to define a respective  
one as an output clock signal.
- 30 6. The phase lock loop according to claim 5, wherein the timing reference signal  
generator is operatively configured to produce an output signal at a characteristic frequency M  
times the frequency of a desired output clock frequency.
- 35 7. The phase lock loop according to claim 6, wherein the number of phases  
represented by the multi-phase output signals are reduced by a scale factor M from a number of  
phases produced by a timing reference signal generator operating at a characteristic frequency  
substantially equal to a desired output clock frequency.
8. The phase lock loop according to claim 7, wherein the phase select MUX is a Gray  
code MUX, the MUX selecting between and among multi-phase signals in accordance with a

1 phase control word, the phase control word changing states in accordance with a Gray code sequence.

5 9. The phase lock loop according to claim 8, wherein the phase control word has a characteristic width J, where J is mathematically dependent on the frequency scale factor M.

10. The phase lock loop according to claim 9, wherein the frequency divider circuit is constructed of current mode logic components.

10 11. The phase lock loop according to claim 9, wherein the phase control MUX is constructed of current mode logic components.

12. A feedback controlled timing circuit, comprising:  
a comparison circuit configured to compare a frequency characteristic of an input  
15 signal to a frequency characteristic of a timing reference signal, the comparison circuit asserting control signals in response to said comparison;

a timing reference signal generator, connected to provide a timing reference signal to the comparison circuit, the timing reference signal generator responsive, in feedback fashion, to said control signals asserted by the comparison circuit; and

20 wherein the timing reference signal generator is configured to develop an output signal at a frequency M times the frequency of a desired output clock signal.

13. The timing circuit according to claim 12, wherein the desired output clock signal has a frequency characteristic N times the frequency characteristic of the input signal.

25 14. The timing circuit according to claim 13. further comprising:  
first frequency divider circuitry disposed between the timing reference signal generator and the comparison circuit; and

30 second frequency divider circuitry disposed between the timing reference signal generator and an output, wherein the first and second frequency divider circuitry having different frequency division characteristics.

15. The timing circuit according to claim 14, the first frequency divider circuitry dividing the output signal of the timing reference signal generator by a scale factor ( $N \times M$ ) to develop said frequency characteristic provided to said comparison circuit.

35

1           16. The timing circuit according to claim 15, the second frequency divider circuitry dividing the output signal of the timing reference signal generator by a scale factor M to develop said desired output clock signal.

5           17. The timing circuit according to claim 16, wherein the timing reference signal generator is implemented as a VCO, the VCO constructed as a sequential delay stage.

10           18. The timing circuit according to claim 17, the VCO developing multi-phase output signals, each oscillating at the characteristic frequency of the VCO, and each having a phase relationship characterized by an inherent delay of each delay stage.

15           19. The timing circuit according to claim 18, wherein the number of phases represented by the multi-phase output signals are reduced by a scale factor M from a number of phases produced by a timing reference signal generator operating at a characteristic frequency substantially equal to a desired output clock frequency.

20           20. The timing circuit according to claim 18, further comprising a phase select MUX, the phase select MUX selecting between and among the multi-phase signals to define a respective one as an output clock signal.

25           21. The timing circuit according to claim 20, wherein the phase select MUX is a Gray code MUX, the MUX selecting between and among multi-phase signals in accordance with a phase control word, the phase control word changing states in accordance with a Gray code sequence.

30           22. The timing circuit according to claim 21, wherein the phase control word has a characteristic width J, where J is mathematically dependent on the frequency scale factor M.

35

1/3

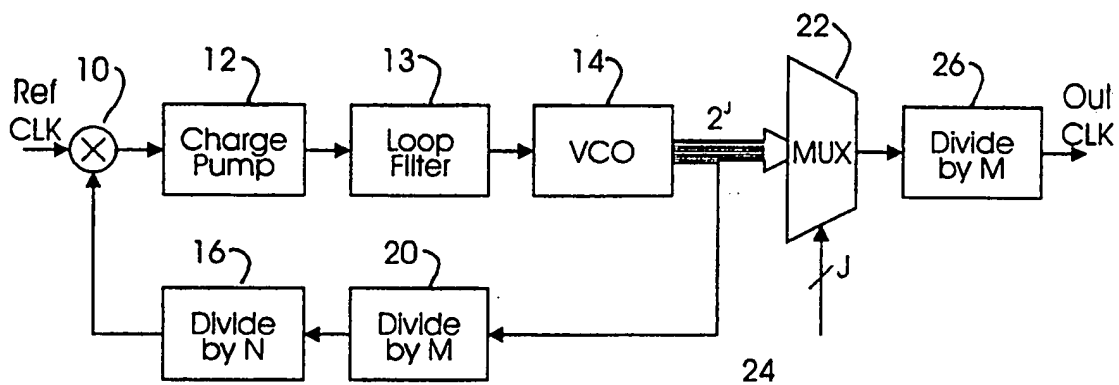


FIG. 1

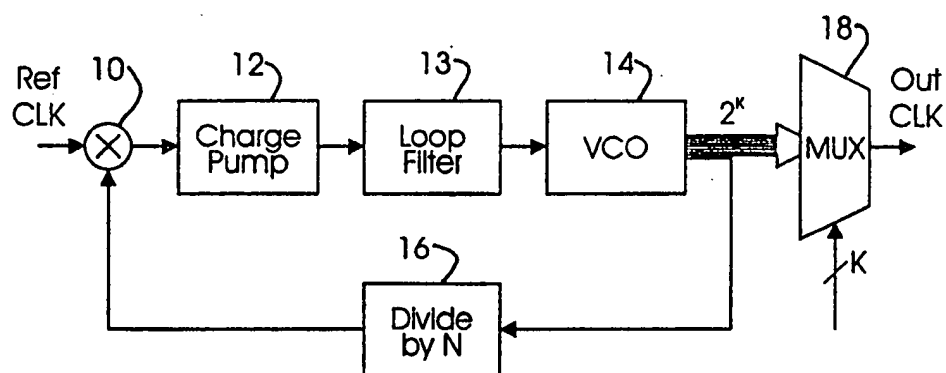


FIG. 2

2/3

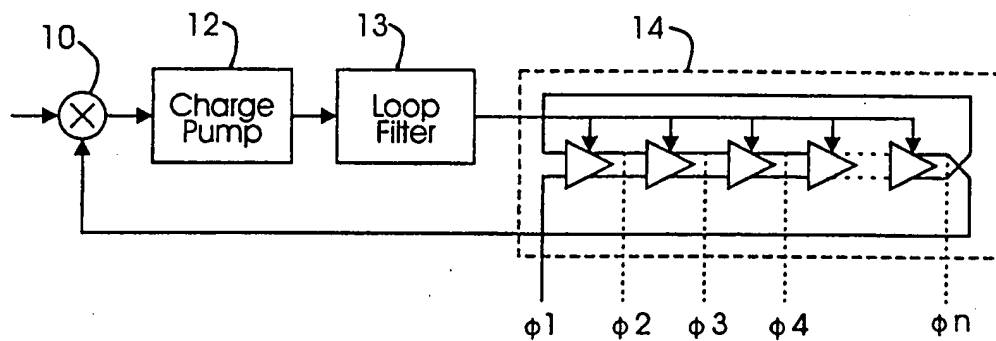


FIG. 3

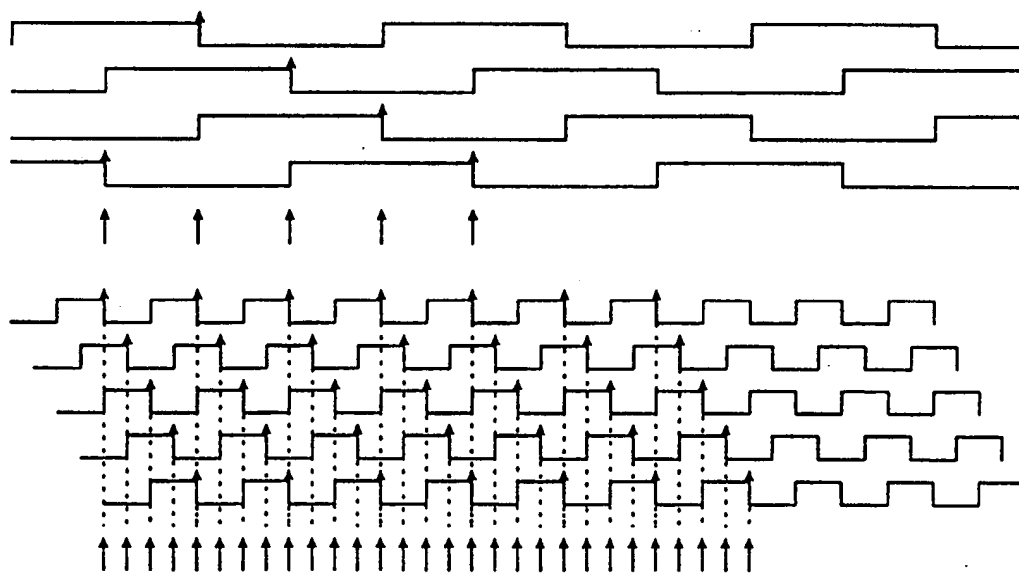


FIG. 4



3/3

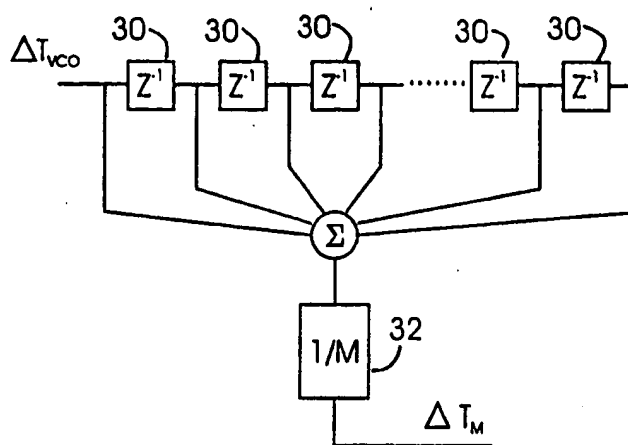


FIG. 5

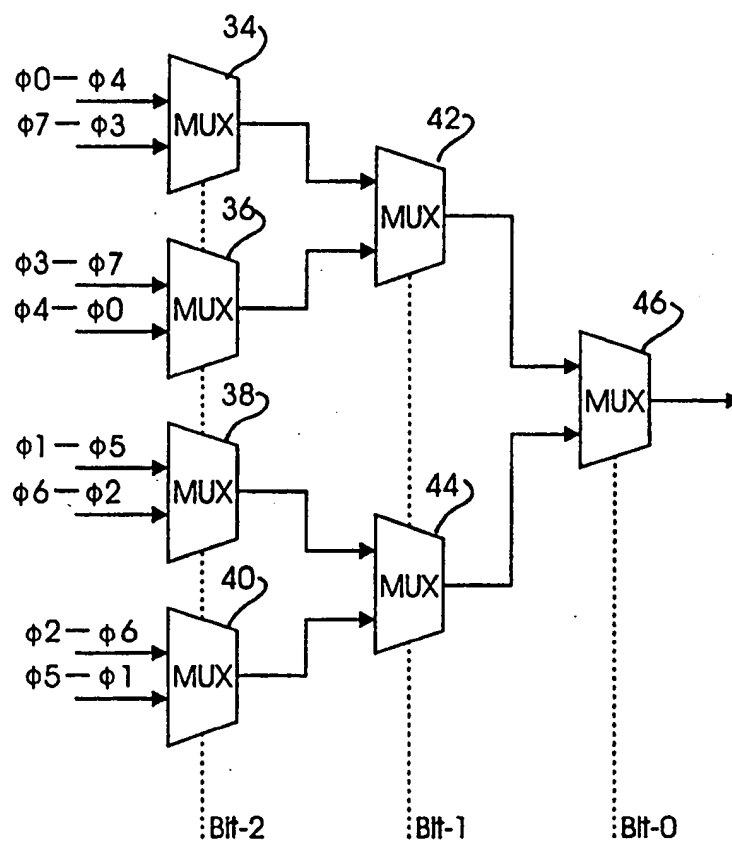


FIG. 6

# INTERNATIONAL SEARCH REPORT

Internat. Application No.

PCT/US 99/29083

## A. CLASSIFICATION OF SUBJECT MATTER

IPC 7 H03L7/183 H03L7/099

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 H03L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 126 691 A (MIJUSKOVIC DEJAN ET AL) 30 June 1992 (1992-06-30) column 2, line 21 - column 7, line 6 column 3, line 51 - line 66 column 4, line 39 - column 5, line 20; table 1 figures 1,2	1-13
Y	---	20-22
X	EP 0 596 656 A (AMERICAN TELEPHONE & TELEGRAPH) 11 May 1994 (1994-05-11) column 1, line 43 - line 49 column 2, line 44 - column 9, line 50 figures 1,2,5	1-7, 12-19
Y	---	20-22
A	---	9-11
	-/--	

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

### \* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search

29 March 2000

Date of mailing of the international search report

11/04/2000

Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2  
NL - 2280 HV Rijswijk  
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,  
Fax: (+31-70) 340-3016

Authorized officer

Balbinot, H

# INTERNATIONAL SEARCH REPORT

Internal Application No

PCT/US 99/29083

## C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 95 19067 A (LEVEL ONE COMMUNICATIONS INC) 13 July 1995 (1995-07-13) page 9, line 15 -page 12, line 21; figure 5 ---	1-7, 12, 13
X	US 5 068 628 A (GHOSHAL SAJOL C) 26 November 1991 (1991-11-26) column 2, line 53 -column 4, line 8; figures 1,2 -----	1-7, 12, 13

# INTERNATIONAL SEARCH REPORT

Information on patent family members

Internat Application No

PCT/US 99/29083

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5126691 A	30-06-1992	NONE	
EP 0596656 A	11-05-1994	US 5268656 A JP 6216730 A	07-12-1993 05-08-1994
WO 9519067 A	13-07-1995	US 5493243 A CA 2180466 A DE 69405016 D DE 69405016 T EP 0738437 A IL 112252 A	20-02-1996 13-07-1995 18-09-1997 15-01-1998 23-10-1996 06-12-1998
US 5068628 A	26-11-1991	US 5159291 A	27-10-1992

**This Page is Inserted by IFW Indexing and Scanning  
Operations and is not part of the Official Record**

## **BEST AVAILABLE IMAGES**

Defective images within this document are accurate representations of the original documents submitted by the applicant.

Defects in the images include but are not limited to the items checked:

- ☐ **BLACK BORDERS**
- ☐ **IMAGE CUT OFF AT TOP, BOTTOM OR SIDES**
- ☒ **FADED TEXT OR DRAWING**
- ☐ **BLURRED OR ILLEGIBLE TEXT OR DRAWING**
- ☐ **SKEWED/SLANTED IMAGES**
- ☐ **COLOR OR BLACK AND WHITE PHOTOGRAPHS**
- ☐ **GRAY SCALE DOCUMENTS**
- ☐ **LINES OR MARKS ON ORIGINAL DOCUMENT**
- ☐ **REFERENCE(S) OR EXHIBIT(S) SUBMITTED ARE POOR QUALITY**
- ☐ **OTHER: \_\_\_\_\_**

**IMAGES ARE BEST AVAILABLE COPY.**

**As rescanning these documents will not correct the image problems checked, please do not report these problems to the IFW Image Problem Mailbox.**